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The State of the Art and Science of Coastal Engineering

Shoreline Response to Future Sea Level Rise

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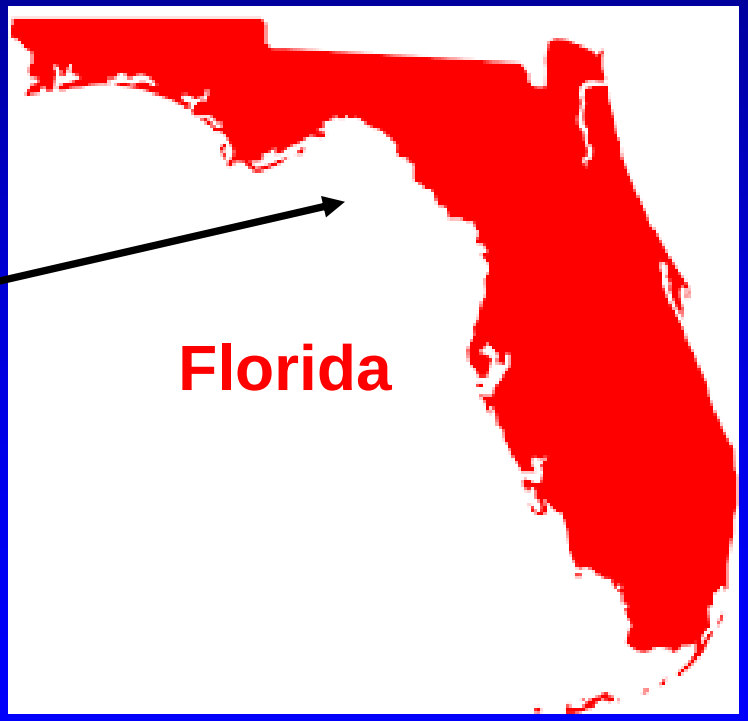
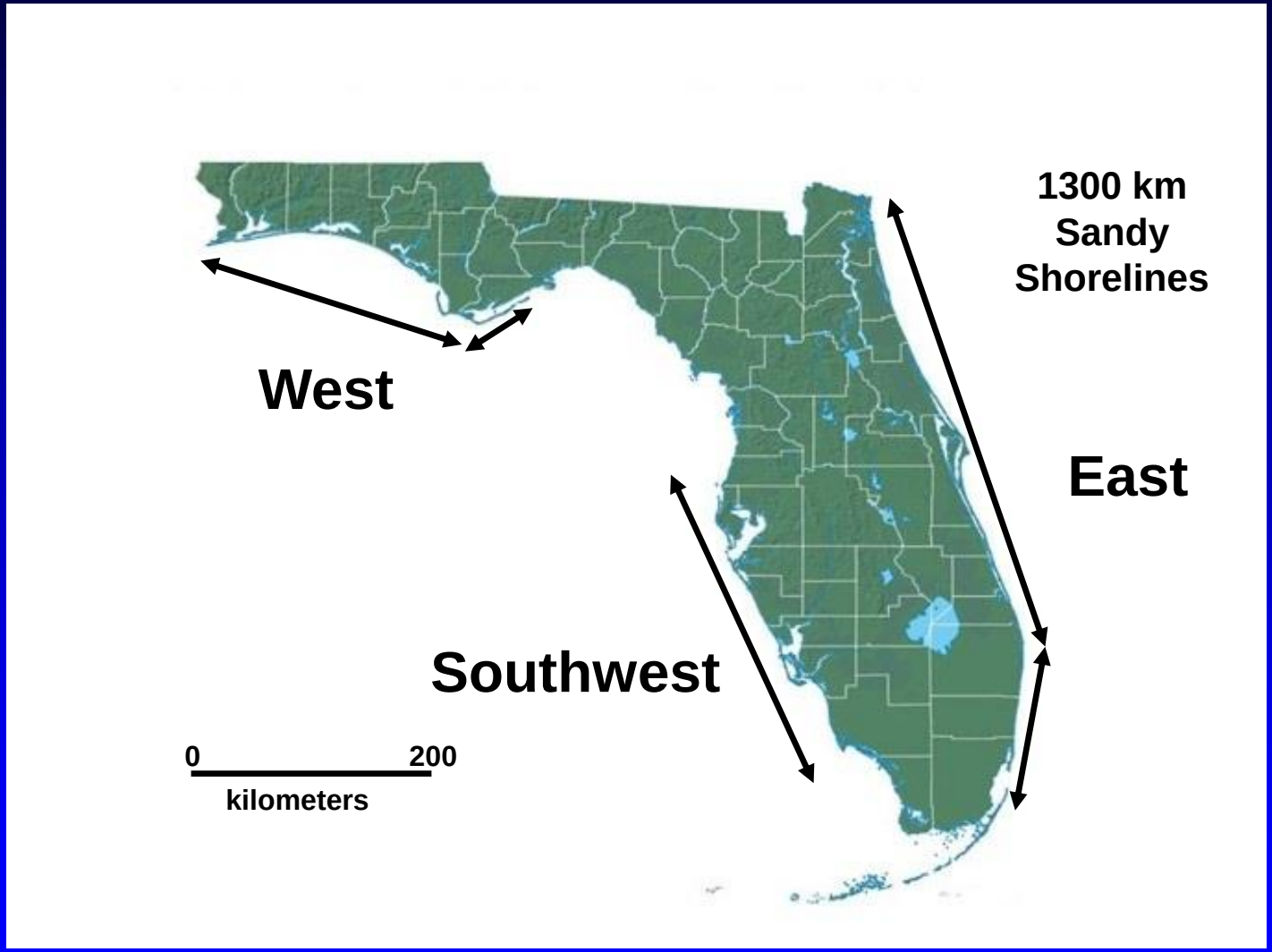
Shoreline Response to Future Sea Level Rise



Florida Sandy Shorelines



Tourism is Its Leading Industry

- Beaches its leading tourist destination
- Consequently, Florida beaches studied extensively


Ft Myers Beach


Destin Beach


St Petersburg Beach


Miami Beach

Shoreline Change

- Shoreline position measurements from 1867- 2015
- Shoreline change

East	+ 50 ± 5 m
Southwest	+ 35 ± 15 m
West	- 25 ± 10 m

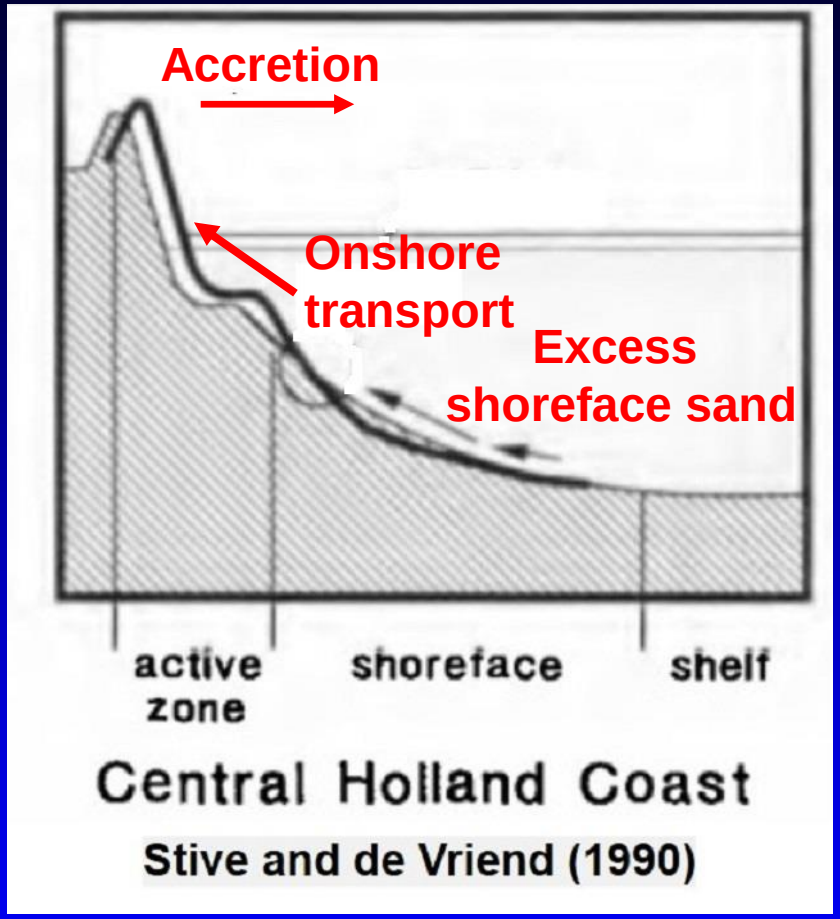
- 1867 to before beach nourishment (1970, 1985)

East	+ 25 ± 5 m
Southwest	+ 5 ± 10 m
West	- 30 ± 10 m

Measurement Locations

Accretion/Erosion

- Netherland's central coast has accreted since at least 1900
- Similar onshore transport on Florida's east/southwest coasts (Houston & Dean, 2014; Houston, 2015)



- In contrast, the Florida west coast has eroded like many world coasts

Florida West Coast

Understand the Past to Project the Future

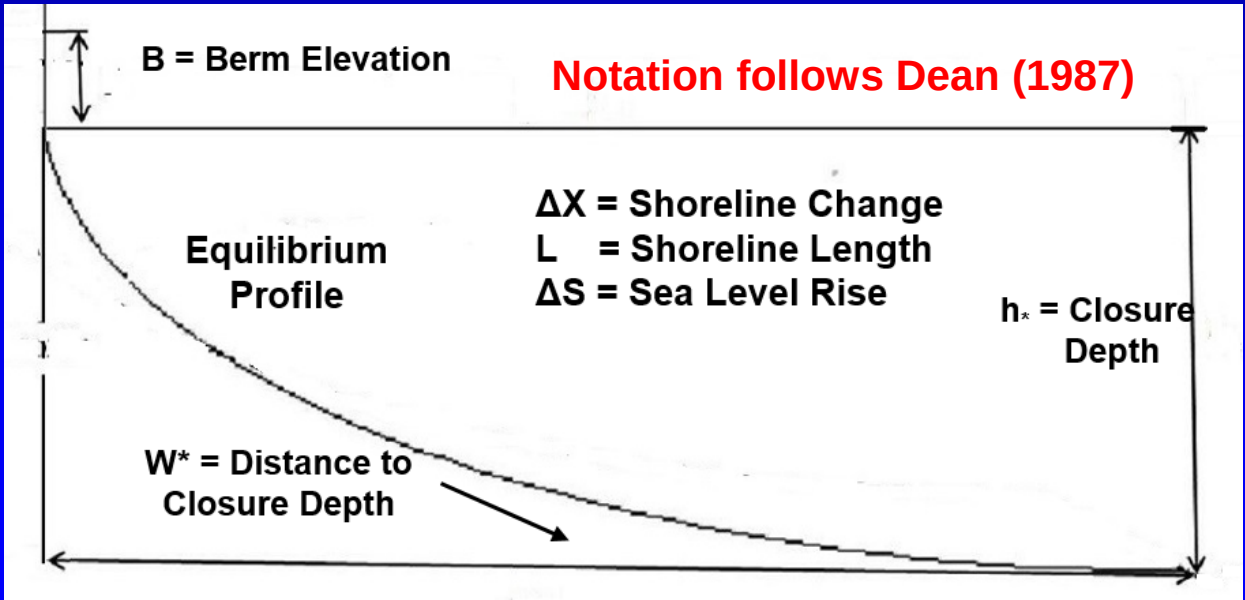
- **Past (1867 - 2015)**
  - Determine shoreline change using measured data
  - Quantify processes causing this change
- **Future (50 year and to 2100)**
  - Project shoreline change with increased sea level rise
  - Analyze whether beach nourishment can counter this increased rise

Past Shoreline Change, 1867 - 2015

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Measured Shoreline Area Change	Sea Level Rise	Inlets	Beach Nourishment	Longshore Transport	Long-Term Onshore Transport

- From Dean and Houston, 2016. *Coastal Engineering*, 118, 1-8
- Stive et al (1991) had similar equation for Netherlands coast



Past Shoreline Change, 1867 - 2015

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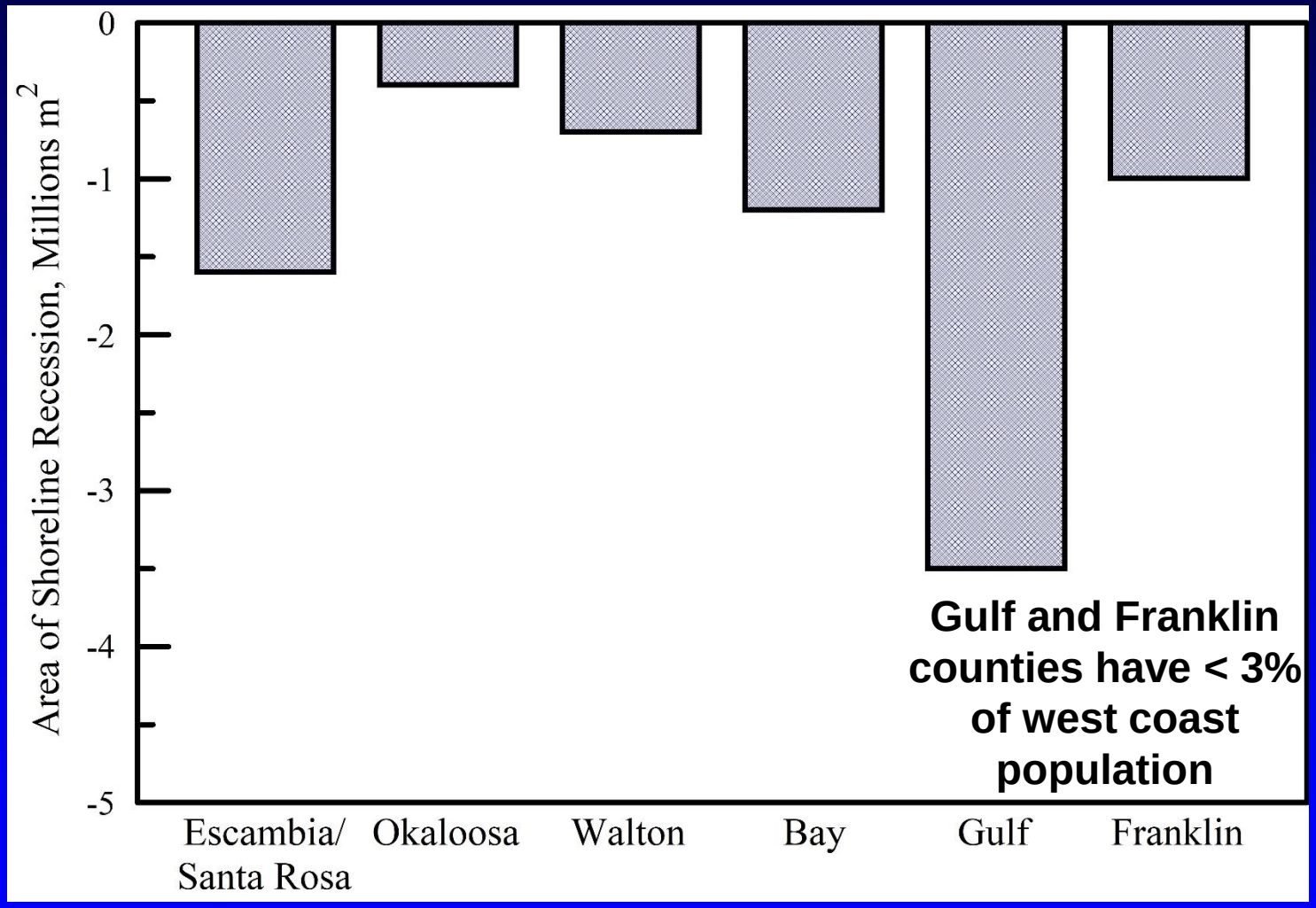
Measured Shoreline Area Change	Sea Level Rise	Inlets	Beach Nourishment	Longshore Transport	Long-Term Onshore Transport

Measured Past Shoreline Change 1867 - 2015

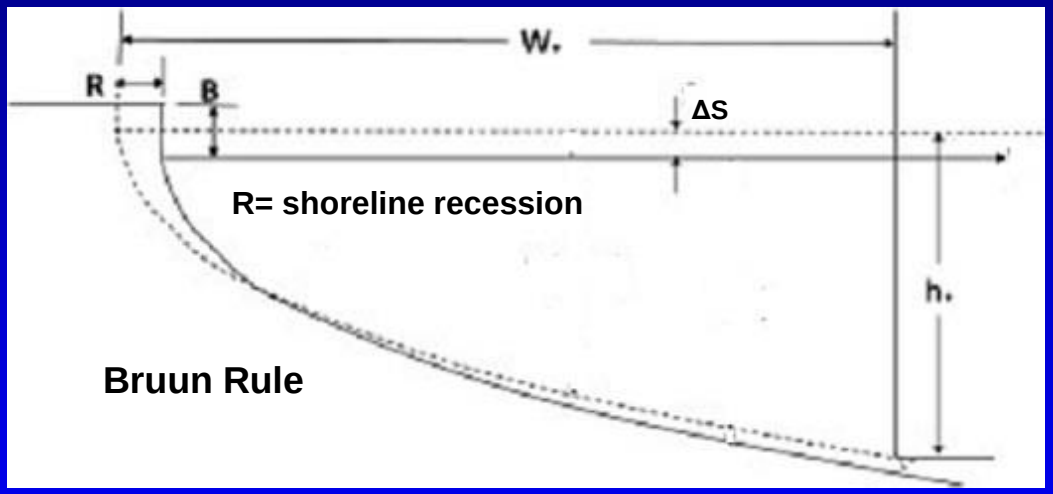


Sea Level Rise

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Measured Shoreline Area Change	Sea Level Rise (Bruun Rule)	Inlets	Beach Nourishment	Longshore Transport	Long-Term Onshore Transport

- **Why the Bruun Rule?**
- **Works when sea level rise dominates shoreline change**
  (Zhang et al, 2004; Passeri et al, 2014)



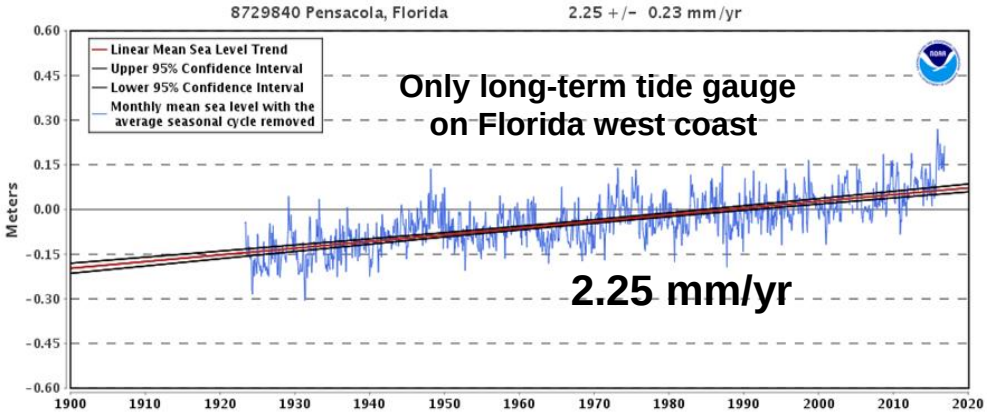
- **However, sea level rise usually does not dominate**
  (Zhang et al, 2004)

Sea Level Rise, 1867 - 2015

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Measured Shoreline Area Change	Sea Level Rise (Bruun Rule)	Inlets	Beach Nourishment	Longshore Transport	Long-Term Onshore Transport

Rise, 1867 - 2015



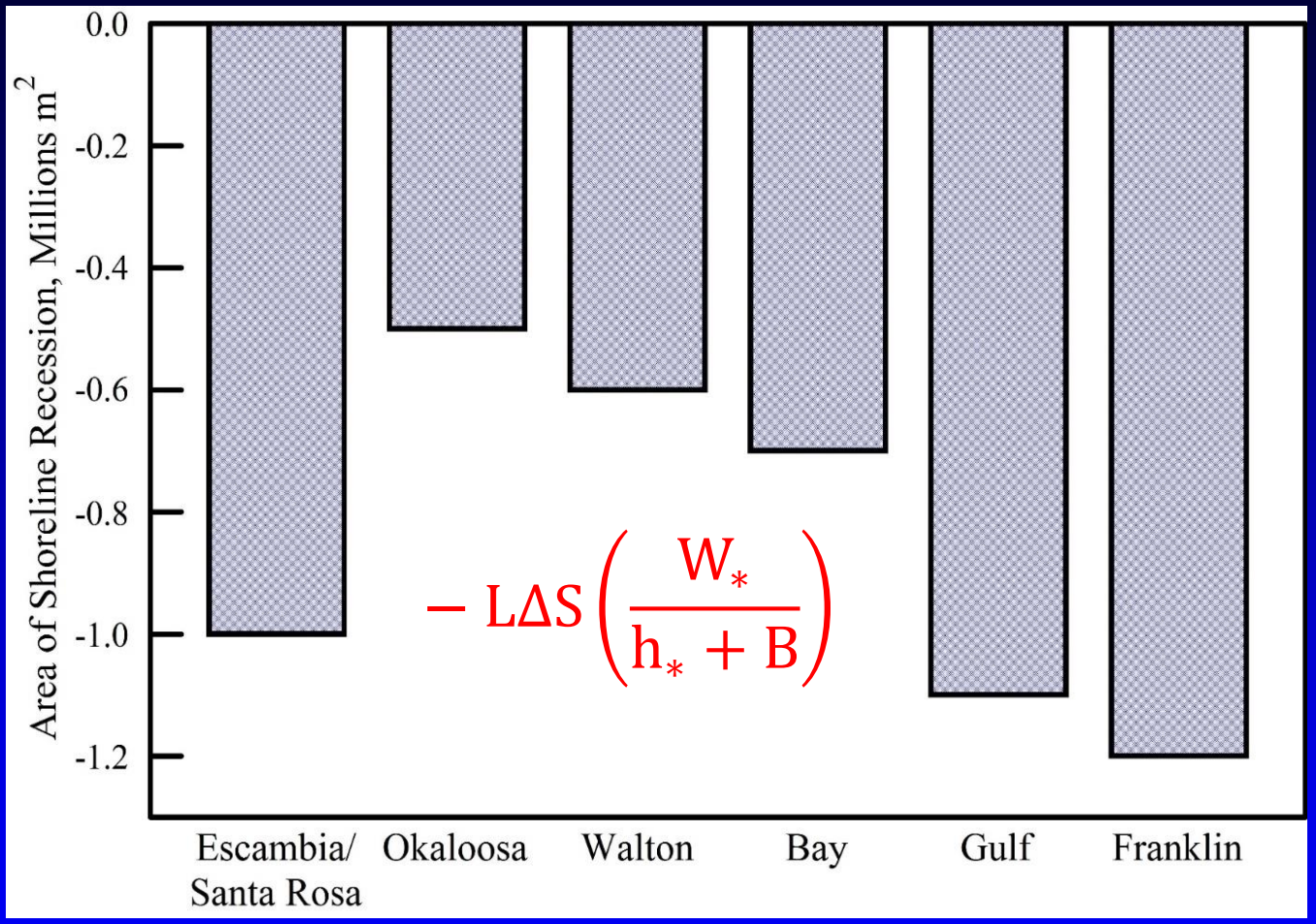
Pensacola Tide Gauge, 1923-2015

Period	Rate mm/yr	Total m
1923-2015	2.25	0.21
1867-1923	1.70	0.09
1867-2015		0.3

References:

- Church and White (2016), NOAA (2016), Systeme d'Observation du Niveau des Eaux Littorales (2016)

Area Change, Sea Level Rise, 1867 - 2015



L = Shoreline length **h_* = Closure depth** **W_* = Distance B to h_***

ΔS = Sea level rise **B = Berm elevation**

Inlets, 1867 - 2015

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Measured Shoreline Change	Sea Level Rise (Bruun Rule)	Inlets	Beach Nourishment	Longshore Transport	Long-Term Onshore Transport

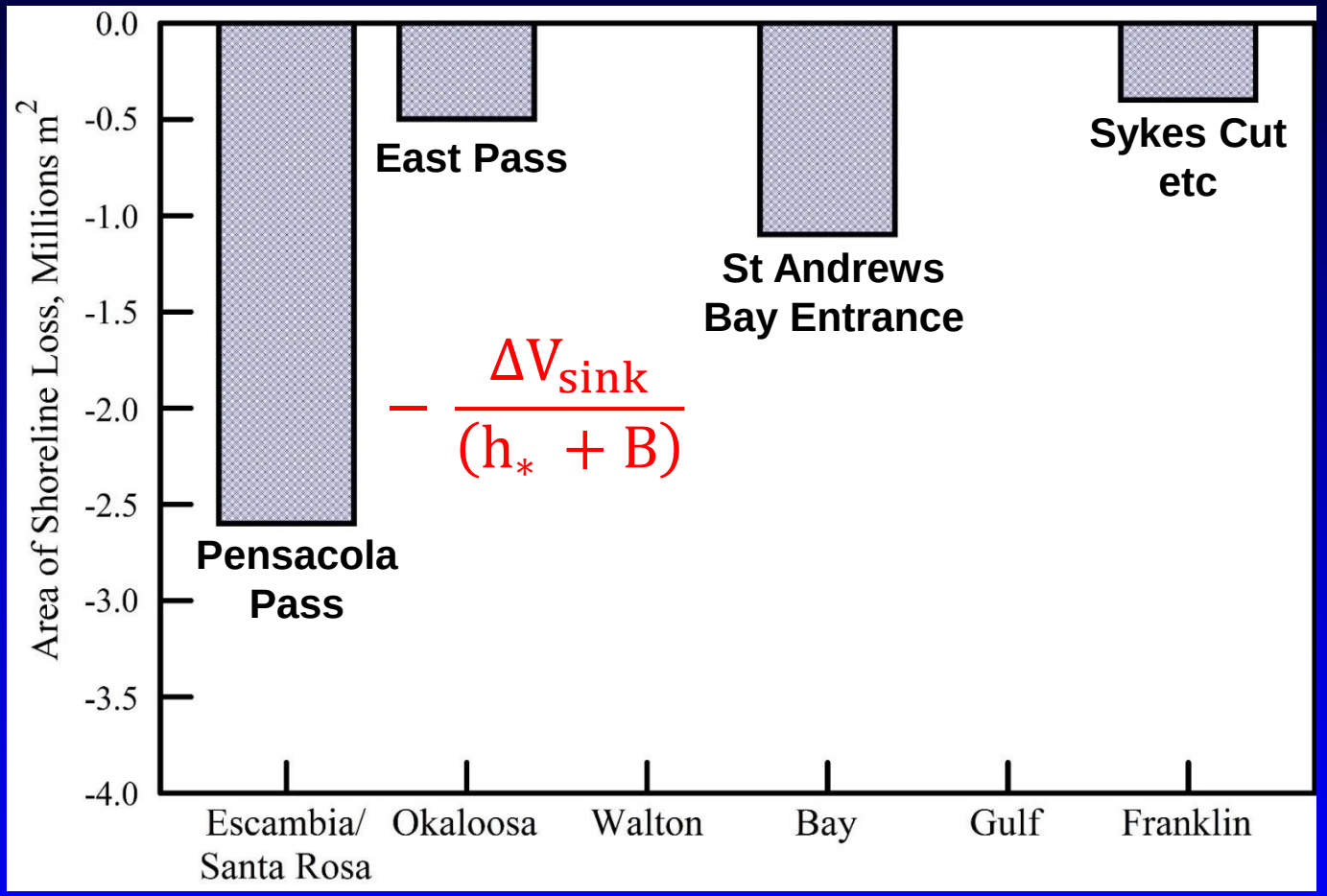
Pensacola Pass

St Andrews Bay Entrance

Area Change from Inlets, 1867 - 2015

Losses

- Offshore disposal of dredged sand
- Shoal growth at inlets modified for navigation



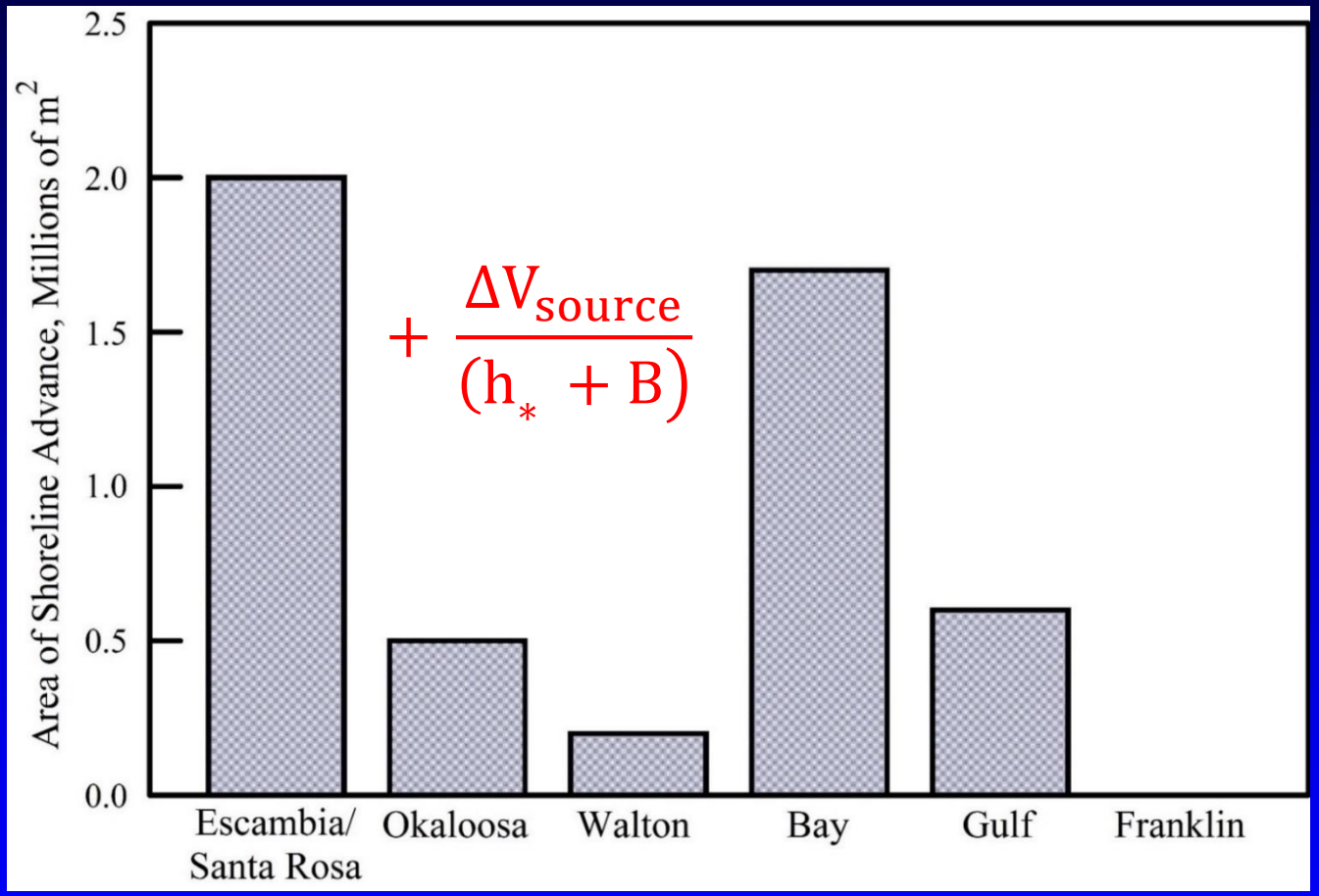
References: Hine et al (1986), Dean and O'Brien (1987), Browder and Dean (1999), Corps of Engineers (2015)

Beach Nourishment, 1867 - 2015

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Measured Shoreline Change	Sea Level Rise (Bruun Rule)	Inlets	Beach Nourishment	Longshore Transport	Long-Term Onshore Transport

Area Change from Beach Nourishment 1985 - 2015

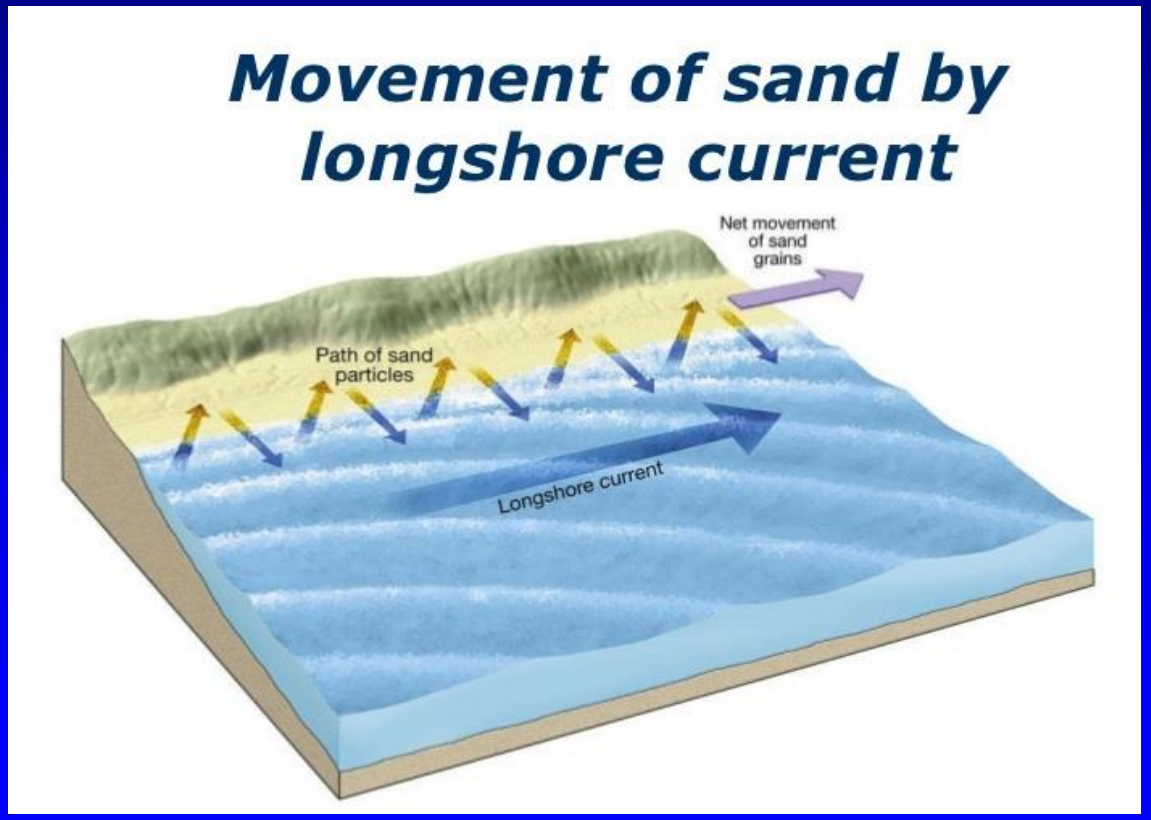


Reference: Florida Department of Environmental Protection (2015)

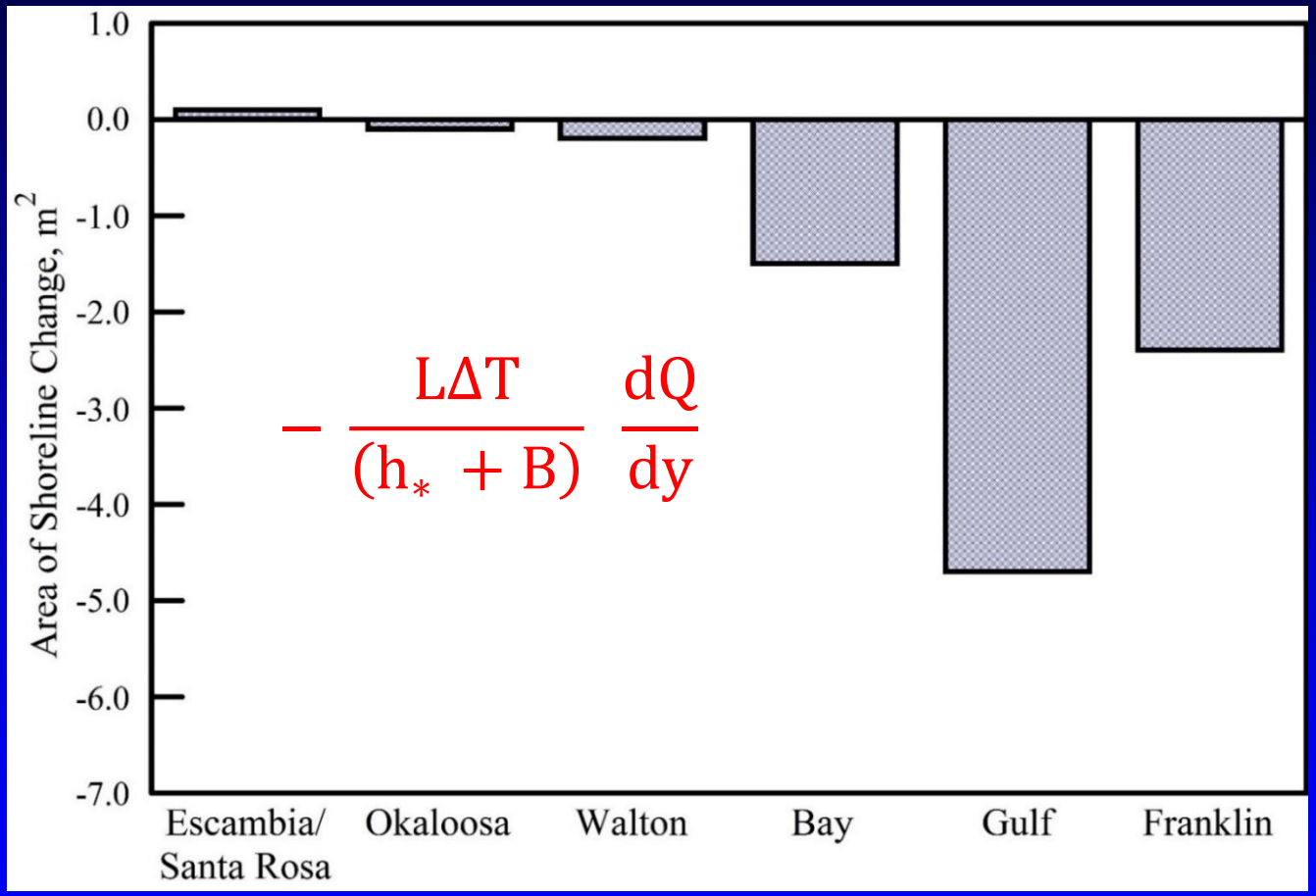
Longshore Transport, 1867 - 2015

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Measured Shoreline Change	Sea Level Rise (Bruun Rule)	Inlets	Beach Nourishment	Longshore Transport	Long-Term Onshore Transport

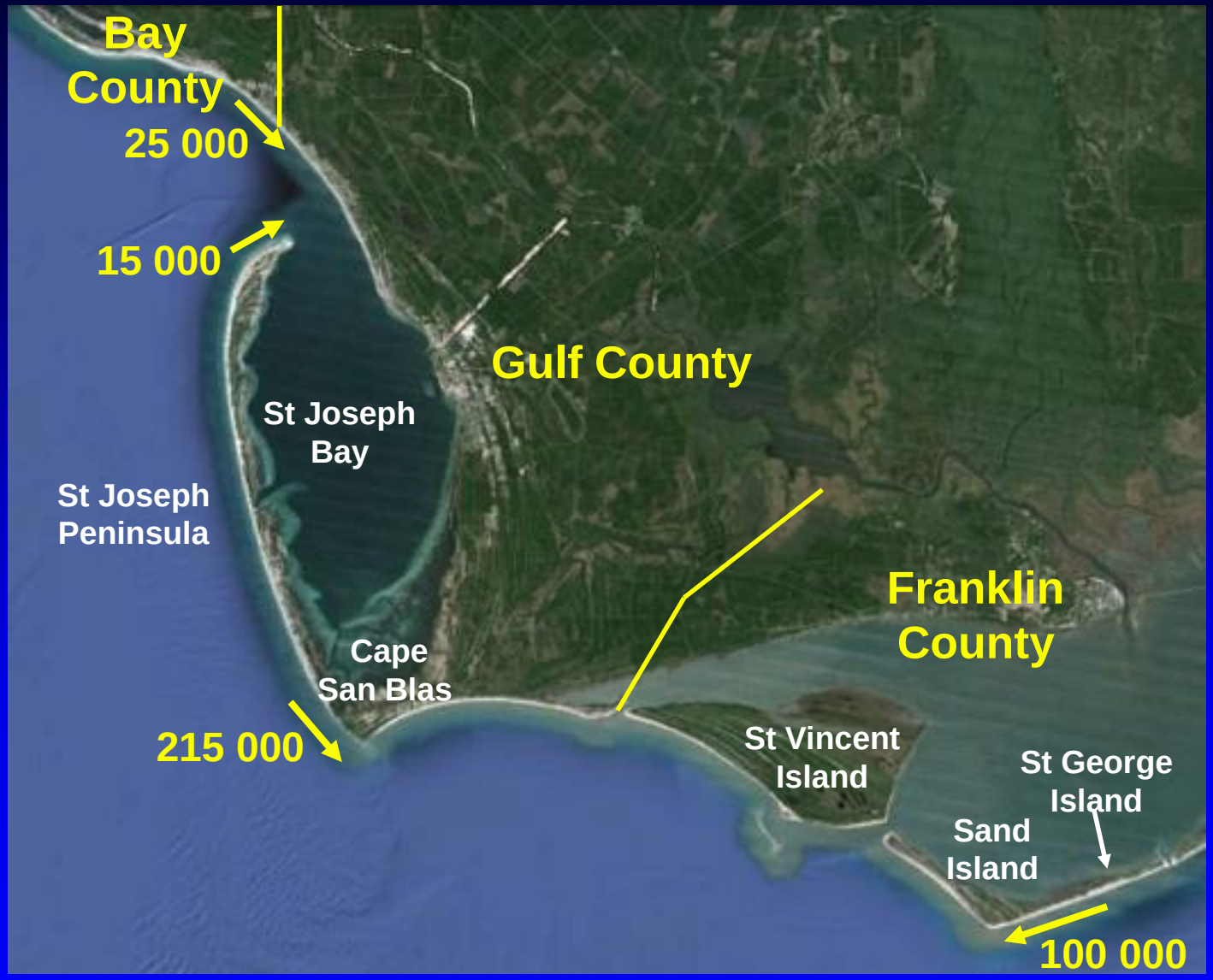


Area Change from Longshore Transport 1867 - 2015



References: Stone and Stapor (1996), Corps of Engineers (2010)

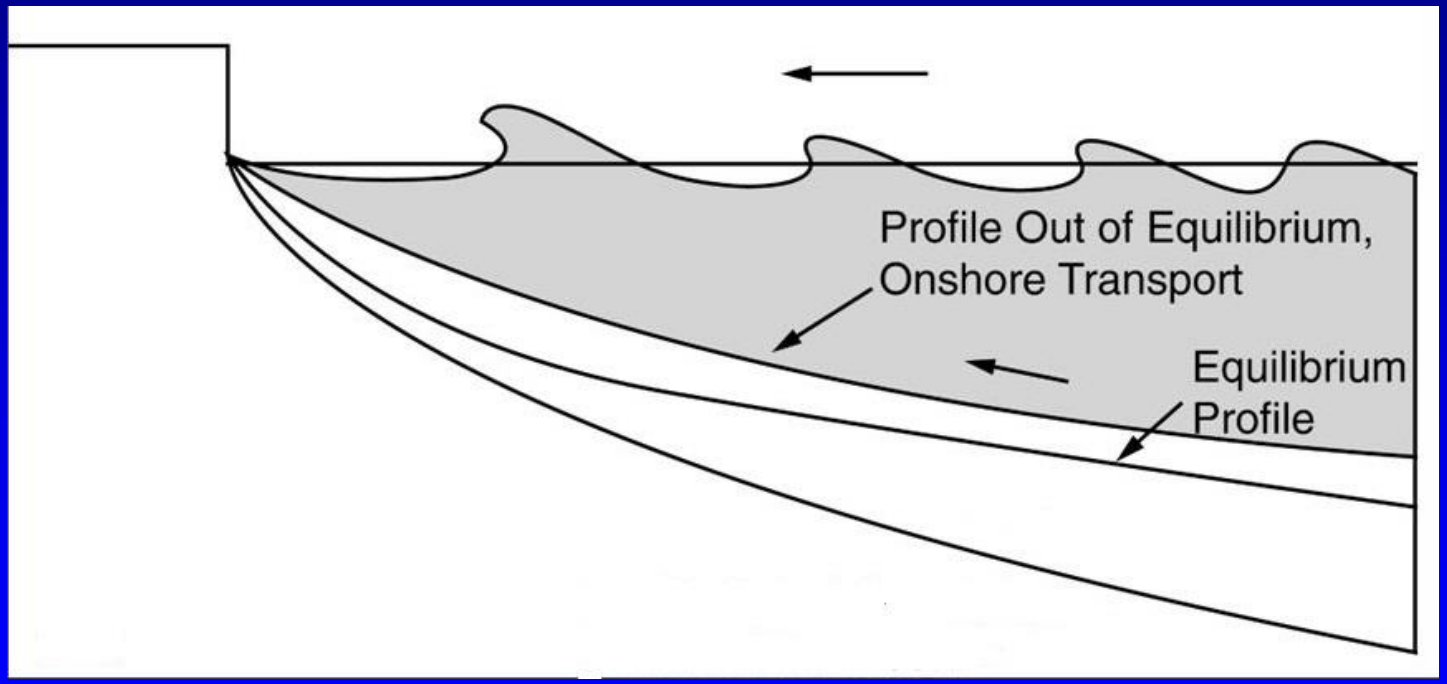
Longshore Transport



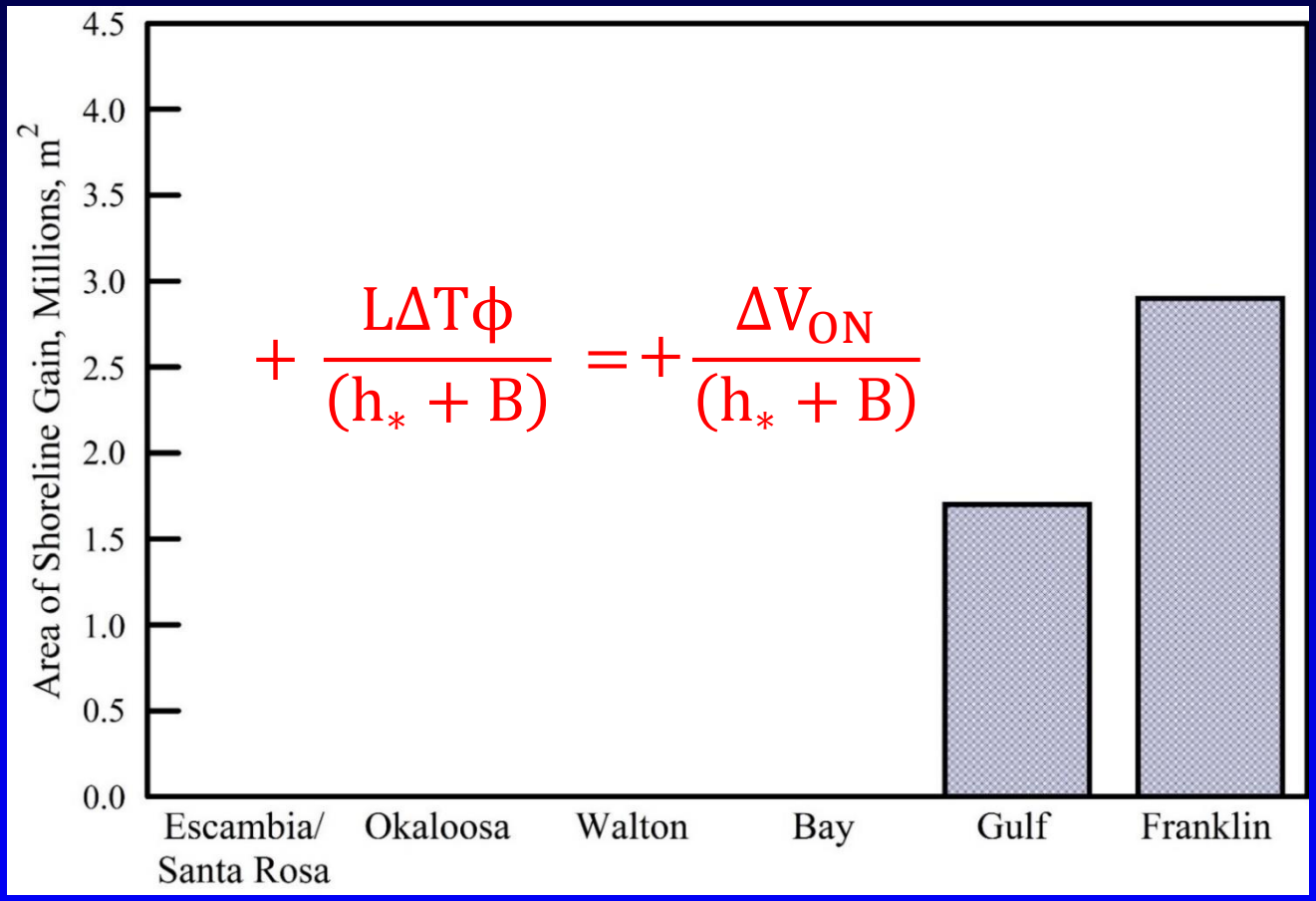
Onshore Transport, 1867 - 2015

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B} - \frac{\Delta V_{sink}}{(h_* + B)}\right) + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Measured Shoreline Change	Sea Level Rise (Bruun Rule)	Inlets	Beach Nourishment	Longshore Transport	Long-Term Onshore Transport

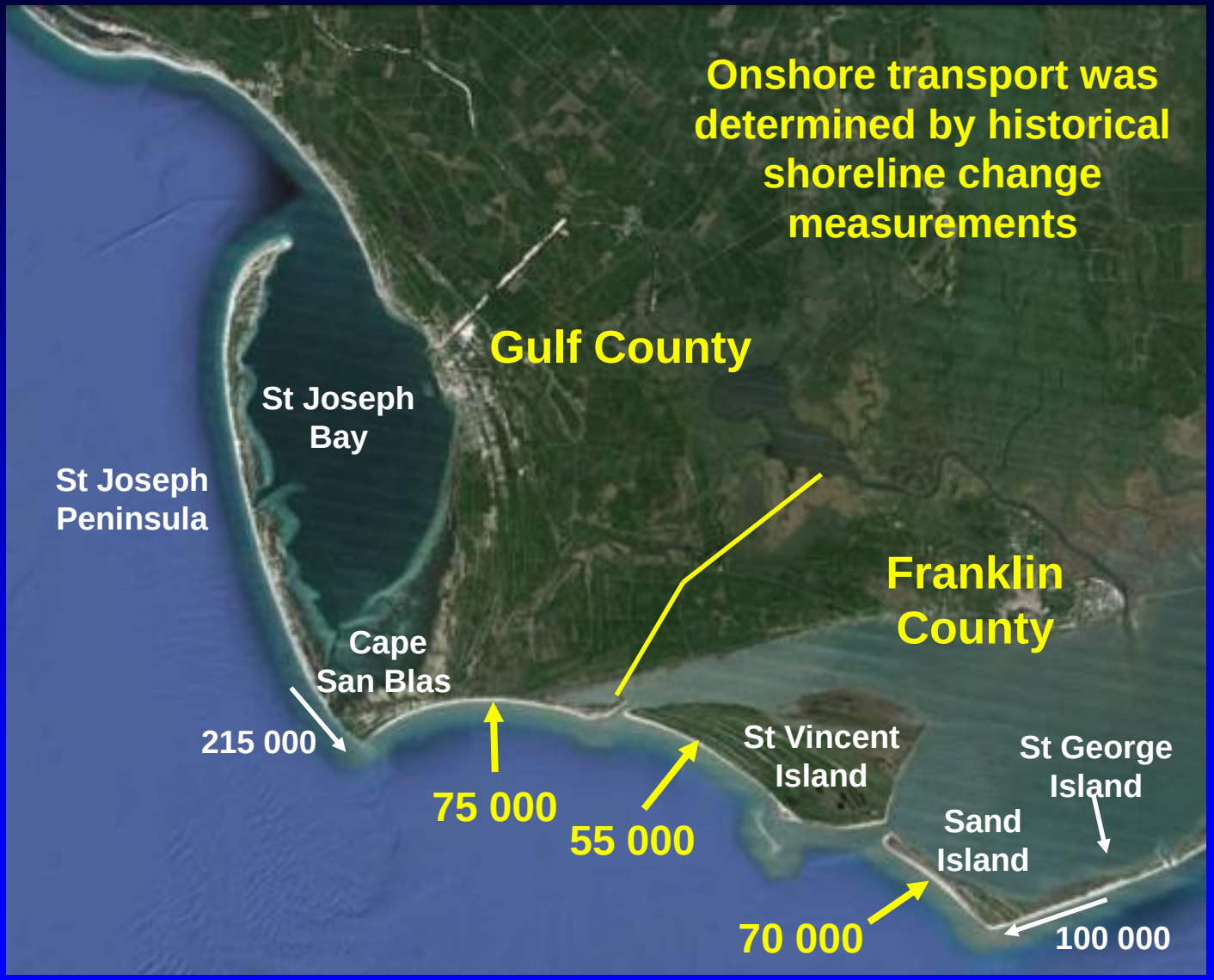


Area Change from Onshore Transport 1867 - 2015

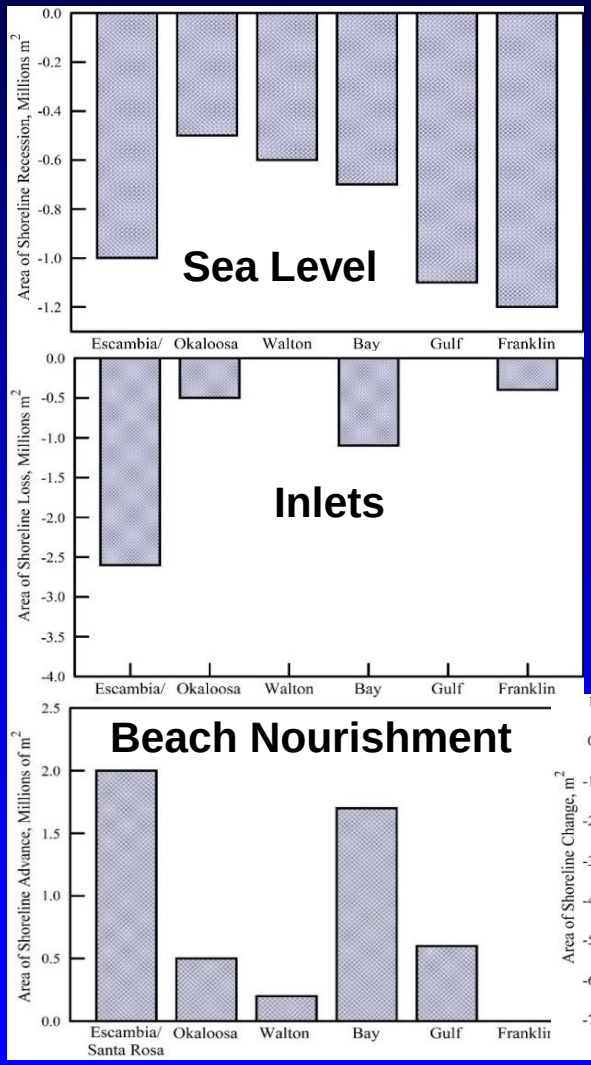


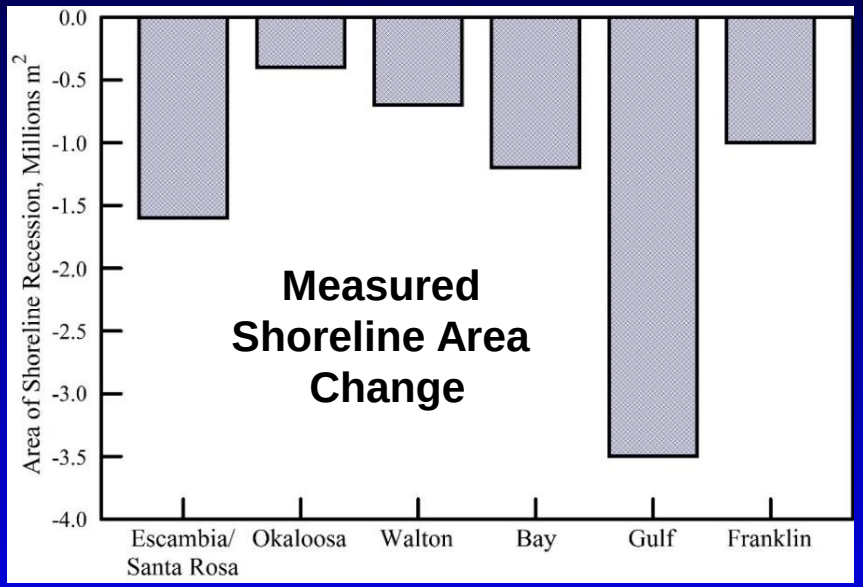
References: Key (1961), Tanner (1987)

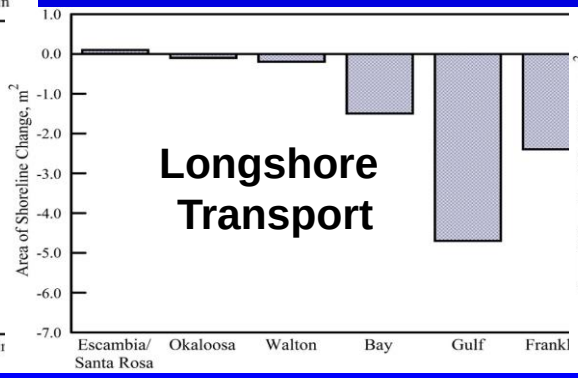
Onshore Transport

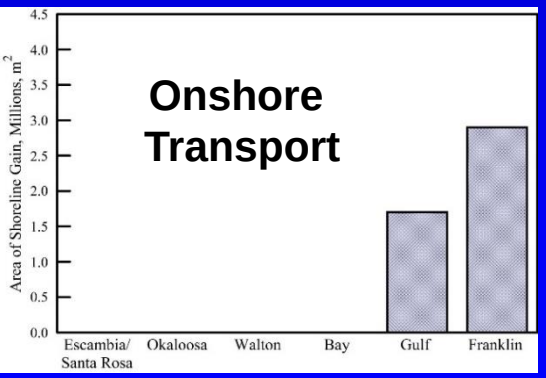


Sum of Estimated Versus Measured Shoreline Area Change, 1867-2015

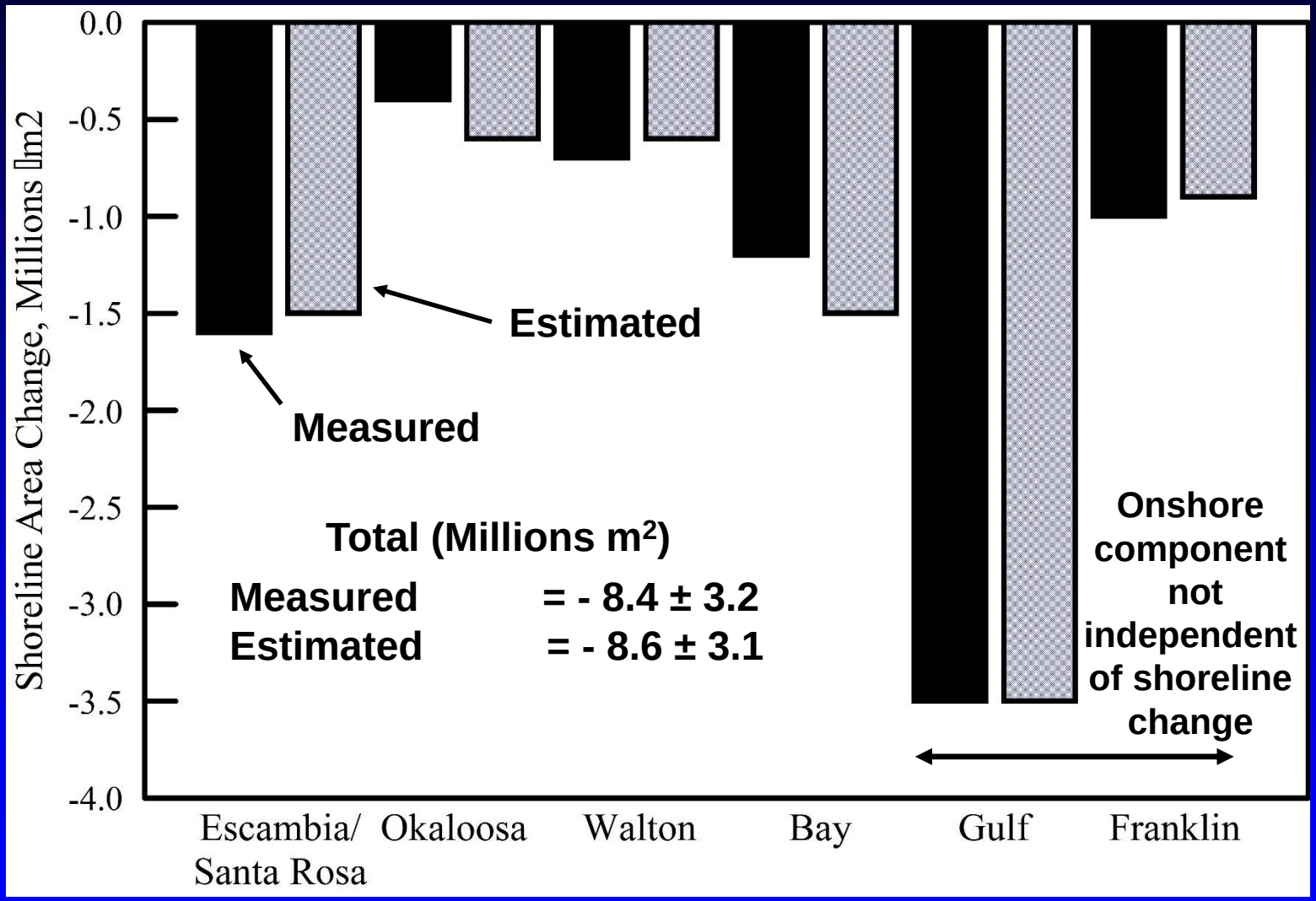




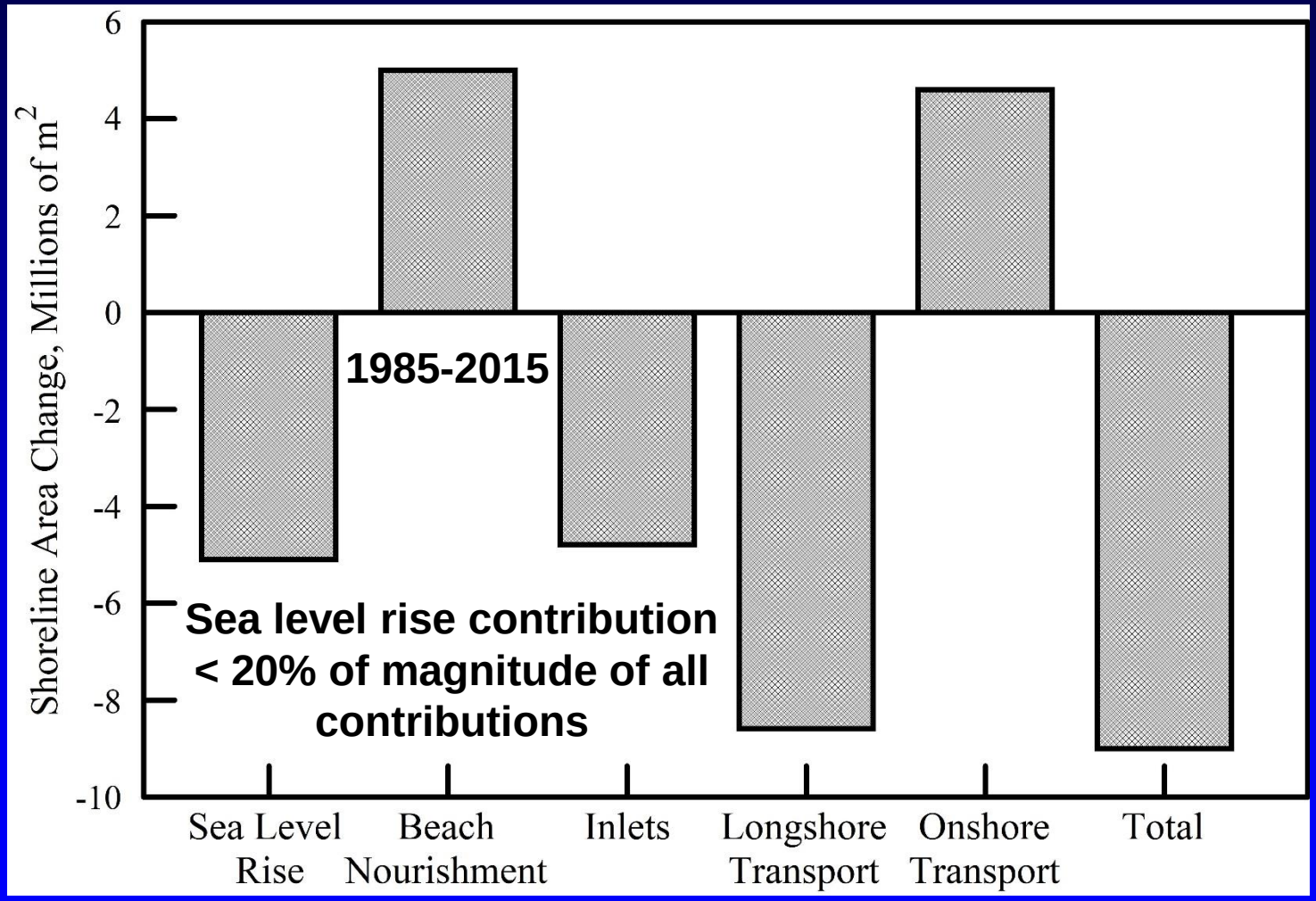




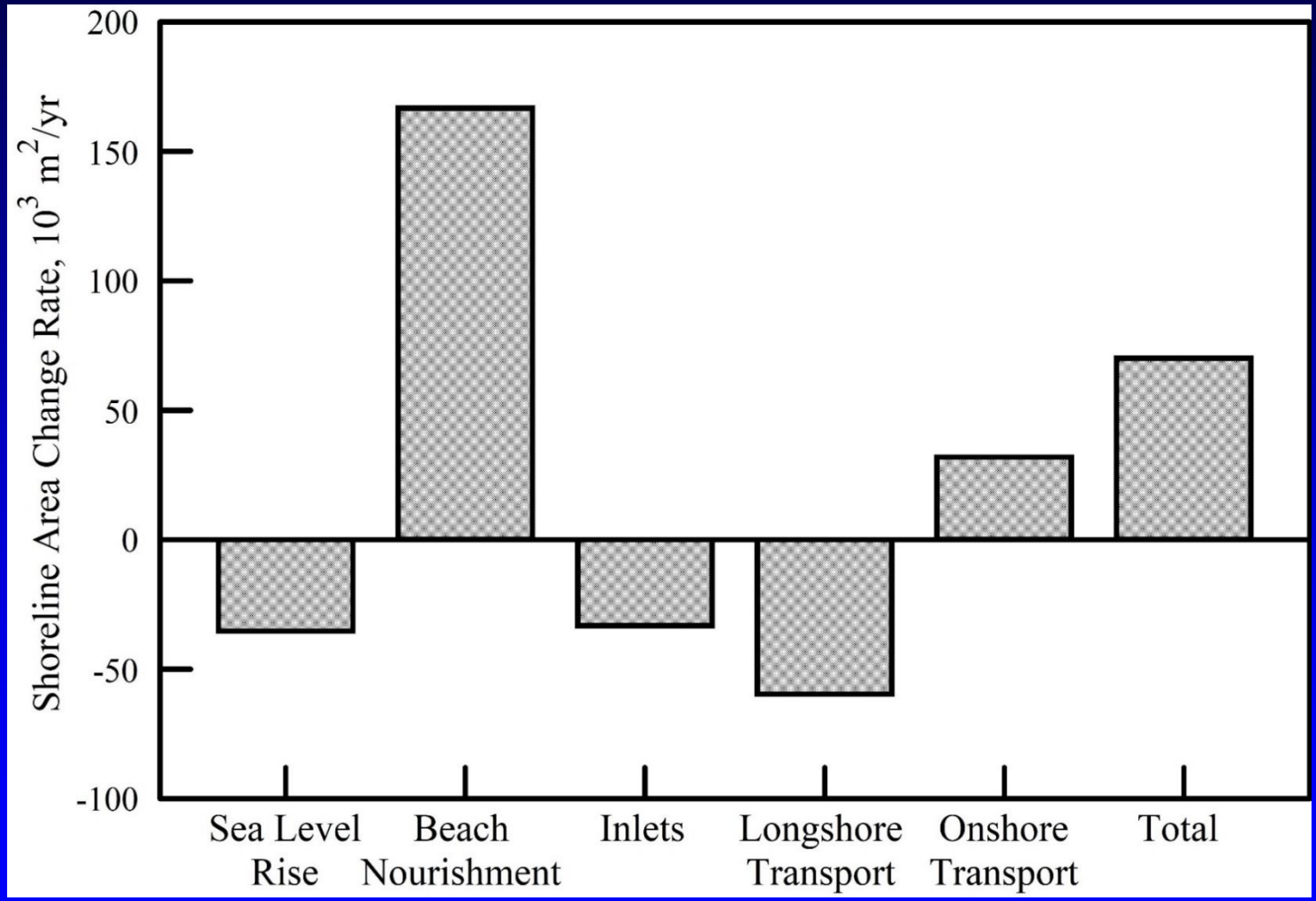
Estimated Versus Measured, 1867-2015



Shoreline Area Change
1867 - 2015



Shoreline Area Change Rate



Future Shoreline Change

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Project shoreline area change

Project shoreline area change produced by each process

2016 - 2065

2016 - 2100

Add

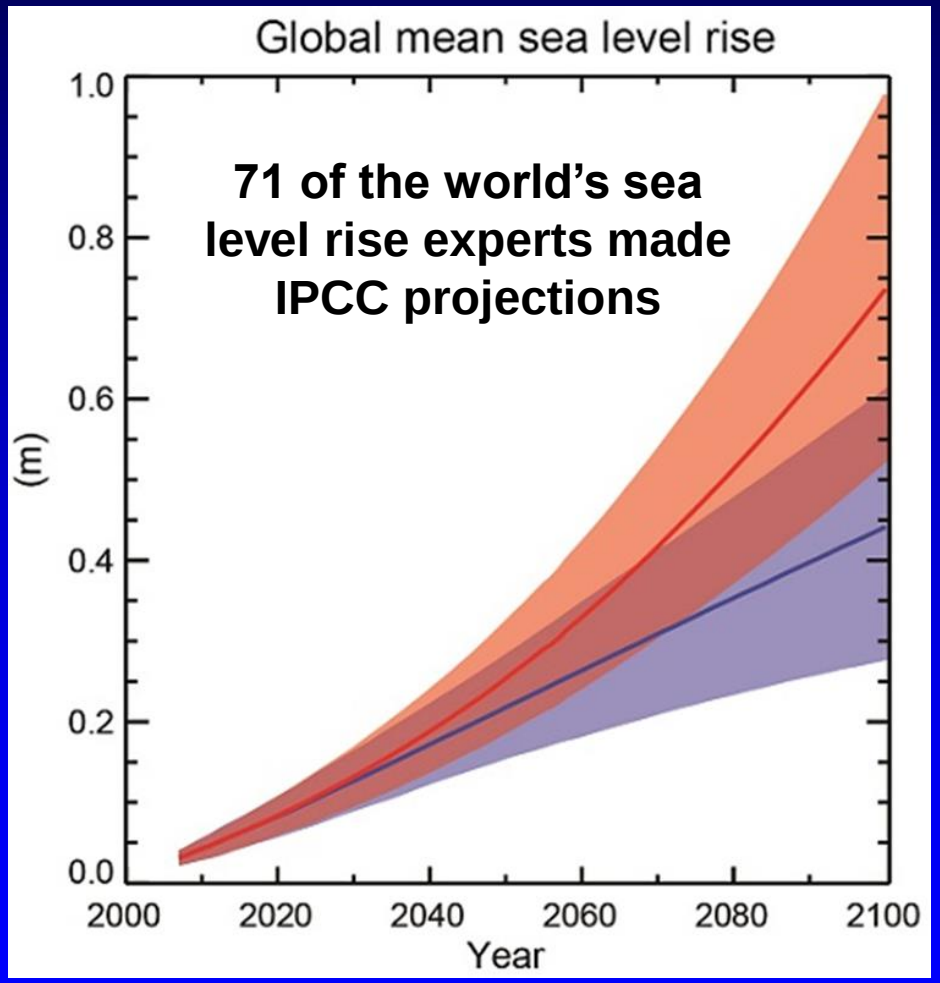
Shoreline Change Projections

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Sea Level

Sea level rise

- Projections of the Intergovernmental Panel on Climate Change (IPCC, 2013)
- IPCC has four carbon-emission scenarios (RCP 2.6, 4.5, 6.0, 8.5)



Shoreline Projections

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Inlets

Inlets

- Changes from past
  - Sand not disposed beyond littoral zone
  - Inlets not being modified, shoals stabilize after ~ 30 years
    (Dombrowski and Mehta, 1996)
- Future
  - Assume shoals rise with sea level to maintain equilibrium with inlet hydrodynamics


Pensacola Pass


St Andrews Bay Entrance

Shoreline Projections

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Beach nourishment

- Initially assume the future rate = past rate
- Vary rate to try to obtain shoreline stability (0.0 m/yr)

Beach Nourishment

Shoreline Projections

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Longshore Transport

Longshore Transport

- **Assume it continues at past rates (Shimura et al, 2011)**

Shoreline Projections

$$L\Delta X = -L\Delta S\left(\frac{W_*}{h_* + B}\right) - \frac{\Delta V_{sink}}{(h_* + B)} + \frac{\Delta V_{source}}{(h_* + B)} - \frac{L\Delta T}{(h_* + B)}\frac{dQ}{dy} + \frac{L\Delta T\phi}{(h_* + B)}$$

Long-Term Onshore Transport

Onshore Transport

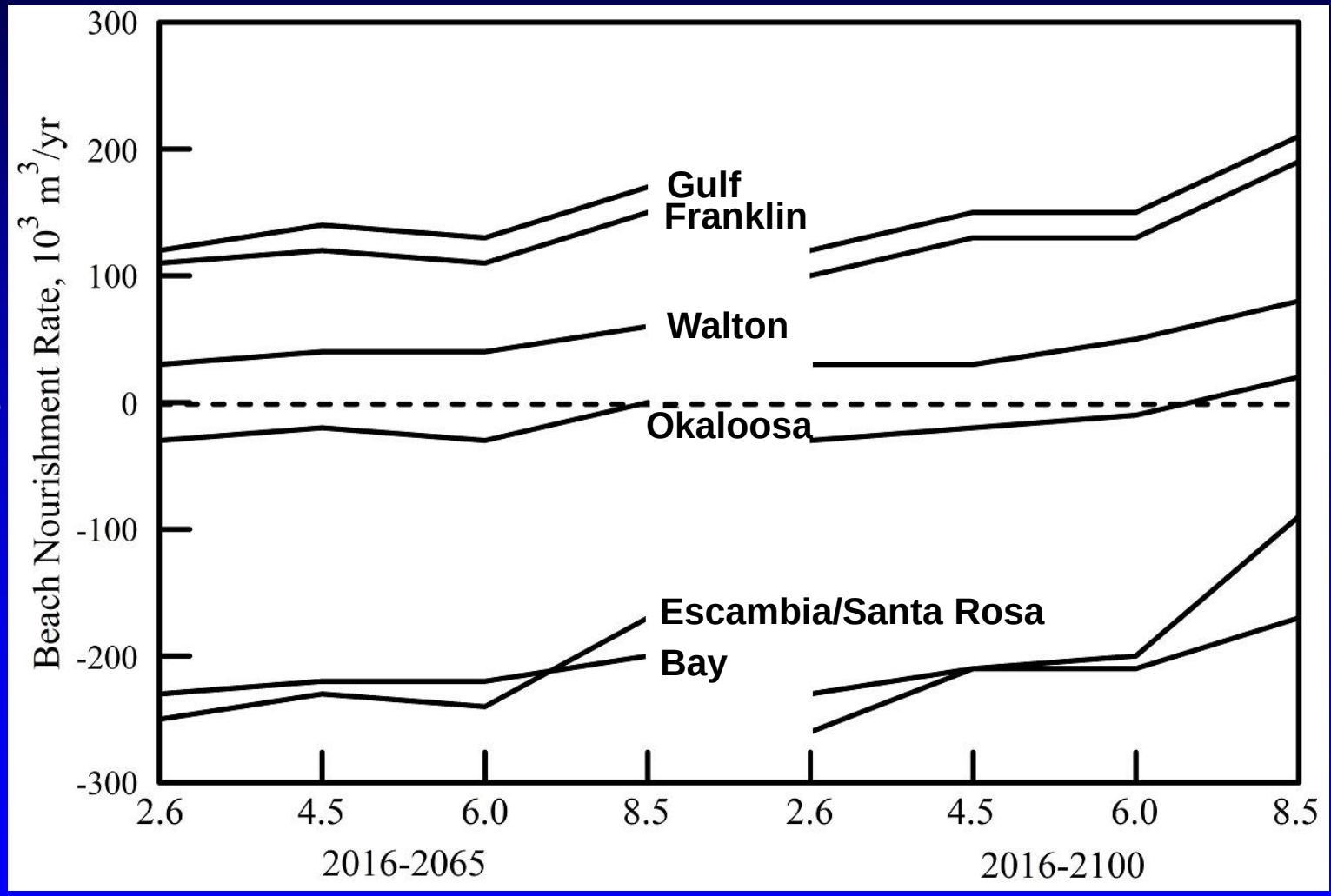
- **Assume it continues at past rates due to large and continuously fed excess sand on the shoreface and steady past shoreline accretion**

Beach Nourishment Relative to Past Rate for Stability (0.0 m/yr)

Nourishment Must be Increased

1985-2015 rate

Nourishment Can be Reduced



Conclusions

- Shoreline projections must include all key processes
- This argues for the need for research to understand these processes
- Beach nourishment is a good adaptation strategy to address sea level rise (if economics support}


The End